PHOSPHORUS REMOVAL FROM HUMAN WASTEWATER BY DIRECT DOSING OF ALUM TO A SEPTIC TANK

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PHOSPHORUS REMOVAL FROM HUMAN WASTEWATER BY DIRECT DOSING OF ALUM TO A SEPTIC TANK

by

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PREFACE

The reduction, and if possible, elimination of artificial inputs of phosphorus to lake waters is an essential part of the control of artificial eutrophication in those lakes. In much of the area of Ontario dedicated to the recreational use of cottages the depth of natural soil (over the Precambrian Shield of intrusive rock) is not adequate to allow the construction of conventional septic tank-tile fields for treatment of domestic sewage, and particularly for the retention of phosphorus by adsorbtion on soil particles.

The following report presents results of a study on a system designed to provide for retention of phosphorus contained in domestic sewage in a standard septic tank.

M. Fielding, P.Eng.

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SUMMARY

In order to protect ground and surface waters from contamination by conventional subsurface sewage disposal systems in areas where a proper soil mantle is not available, the main contaminants in the sewage, such as phosphorus and suspended solids, must be removed from the sewage before the septic tank effluent leaves the tank.

Aluminium sulfate (alum) is well known as a phosphorus removing chemical but it was never used for phosphorus removal in subsurface sewage disposal systems. An original method of dosing alum to a septic tank and the results of removal of phosphorus and other contaminants are presented.

A two compartment septic tank, used exclusively for treatment of toilet waste water, was selected for the study. Background samples taken periodically before the dosing of alum started showed a stable concentration of phosphorus in the septic tank effluent (19.6 $\pm$ 0.5 mg/l as P).

A simple, electrically operated dosing device, was designed in such a way that with each flushing of the toilet a predetermined protion of alum solution was injected into the inlet of the septic tank. The device was located in the basement of the house and connected to the sewer pipe close to the inlet to the septic tank.

As a result of the method of alum injection, an adequate mixing of the alum with the feces and urine in the sewer pipe took place.

The removal of phosphorus from the septic tank effluent depends on the dosing rate of alum or on the Al:P ratio. At a ratio of Al:P ≅ 2 the concentration of the total phosphorus in the septic tank effluent dropped from 19.6 to 0.72 mg/l (as P) i.e. a 96.3% removal of phosphorus was achieved. The dissolved phosphorus level dropped to 0.13 mg/l (as P). Some increase in concentration of sulphates (SO_4) in the septic tank effluent was observed after adding alum, however, the concentrations were lower than those acceptable for SO_4 in drinking water supplies. No adverse effect of the SO_4 on the concrete septic tank or on the soil of the leaching bed was observed.

The precipitation of the phosphorus, suspended solids and other contaminants to the bottom of the tank, caused by the alum, resulted in an increase of the sludge accumulation rate from 62.0 ℓ/pers. year before using alum to 146.0 l/pers. year after the dosing process was introduced. However, the period of time required for the sludge to reach a permissible level in the septic tank (or the cleaning time interval) should not be shorter than 4.4 years.

The simplicity and low cost of the phosphorus removal method seems to justify its use in subsurface sewage disposal systems in areas with high water table or in systems located on bedrock or close to receiving waters.

PHOSPHORUS REMOVAL FROM HUMAN WASTEWATER BY DIRECT DOSING OF ALUM TO A SEPTIC TANK

INTRODUCTION

Phosphorus is considered to be a key element in the excessive fertilization of natural waters or eutrophication which brings about an abundant growth of algae and other aquatic plants leading to deterioration of water quality. Vollenweider (1968) and Thomas (1973) demonstrate numerous examples of eutrophication of lakes in North America and Europe caused by phosphorus entering the lakes from different sources. Human activity and especially inadequately treated human wastewater is one of the sources. Kolenbrander (1970) showed that 38% of the total accumulation of phosphorus in fresh surface waters in The Netherlands come from untreated sewage.

The phosphorus found inside a septic tank comes from human food consumption and from detergents used in the laundry and kitchen. The average amount of phosphorus disposed with domestic sewage is about 0.8 kg/person year (Vollenweider - 1968). Kolenbrander (1972) stated that in The Netherlands each person disposes of 1.4 kg of phosphorus annually, 0.5 kg in excreta 0.8 kg from detergents and 0.1 kg from other sources.

It is generally accepted that most of the phosphorus found in excreta is in a form of orthophosphates (PO_4^{-3}). In cleaning agents phosphorus occurs in a form of polyphosphates (tripolyphosphates or pyrophosphates) but they are quickly hydrolyzed to orthophosphate in sewage water.

Generally, there are no standards or regulations limiting the level of phosphorus concentration in effluent before discharging it into ground waters. Some wastewater treatment plants in the United States and Canada are required to have a maximum phosphorus concentration of 1.0 mg/l (as P) in accordance with the recommendations of the 1972 Canada-United States Agreement on Great Lakes Water Quality (Agreement - 1972). The Swedish law governing environmental protection requires 0.3 to 0.6 mg/l (as P) (Ulmgren - 1975).

It was observed that when subsurface disposal systems are built on proper soil containing sufficient quantities of fine grain particles, like clay and silt, and when the systems are located at proper distances from the receiving water body the removal of the phosphorus from the septic tank effluent by the soil is almost complete (Brandes - 1976). However, when the distances between the disposal system to the lake are limited or in cases when only coarse sand or even bare bedrock are the media separating the disposal system from the water, the phosphorus from the system moves directly into the ground water or into the lake or river. In such cases, it seems quite reasonable to remove the phosphorus from the sewage before the septic tank effluent leaves the tank.

The purpose of this study was to develop a simple and inexpensive method for separating the phosphorus from the wastewater inside the septic tank, at least to levels acceptable for surface discharge (1.0 mg/l).

2. MATERIALS AND METHODS

2.1 Septic Tank and Wastewater Characteristics

A two storey house in Hawkestone, Ontario, using a conventional subsurface sewage disposal system (septic tank - leaching bed) for the treatment of toilet wastewater was selected for the study (Fig. 1). Such a septic tank, where no laundry and kitchen wastes were treated and which served only three residents of approximately constant dietary intake, a greater stability of the chemical and physical properties of the sewage could be expected. In fact, the background samples of the septic tank effluent, taken periodically before alum was applied to the system, have shown a high stability in concentration of the total phosphorus in the effluent. The concentration of phosphorus was 19.6 ± 0.5 mg/l (as P). Also the concentrations of some other components of the septic tank effluent like total solids 596.7 ± 38.3 mg/l, ammonia 130.8 ± 16.1 mg/l, sulphate 50.2 ± 5.9 mg/l, chloride 100.2 ± 4.4 mg/l, calcium 22.7 ± 2.1 mg/l, sodium 101.3 ± 8.1 mg/l, and potassium 38.5 ± 2.4 mg/l, were found to be within limits of ± 12.5% from the average values.

The dimensions of the two compartment septic tank are given in Table 1.

Table 1. Septic Tank Dimensions

Septic Tank.	Bottom Area (m^2)	Depth of Sewage (m)	Volume of Sewage (litres)	(%)
Compartment I	2.033	1.20	2439	71.5
Compartment II	0.810	1.20	972	28.5
Total	2.843	1.20	3411	100.0

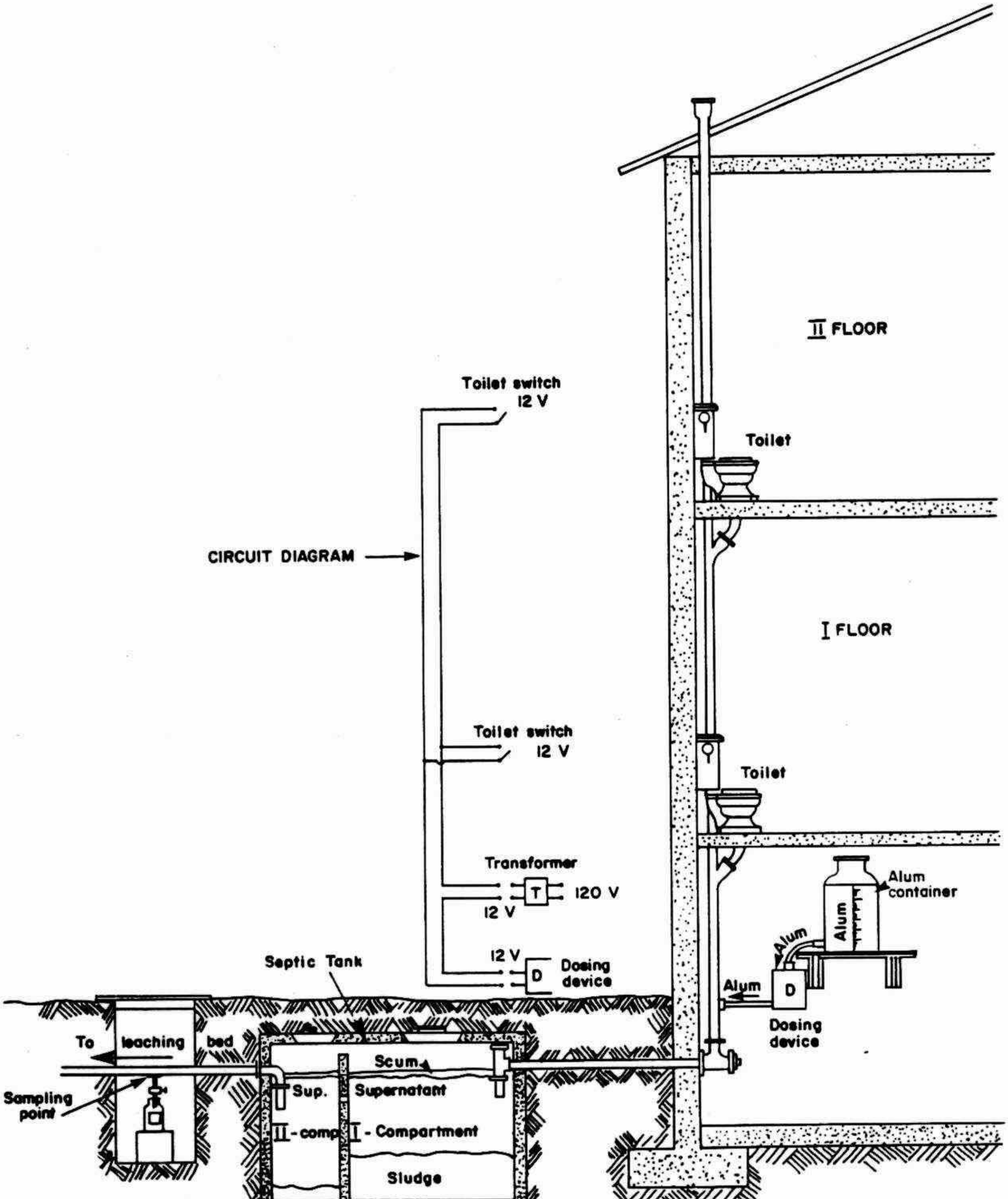

Fig. 1. Dosing of alum to a septic tank.

The septic tank was pumped out on October 10, 1972 and was used for the phosphorus removal study till June 2, 1976 when the last sludge samples were taken and the tank was pumped out again. Regular dosing of alum to the septic tank started on February 13, 1975. Before starting regular dosing of alum, background samples of the septic tank effluent and of the sludge were taken and tested for chemical and bacteriological contaminants.

The amount of toilet water used by the residents was determined by counting the number of toilet flushings by means of two counters attached to the flushing mechanisms.

The average daily discharge of toilet water into the septic tank was 102.6 litres per person per day (l/p.d.). An additional amount of about 15.0 l/p.d. of water was also discharged into the same septic tank while using the bathroom sink. The total use of water or, the average production of wastewater, was 117.6 l/p.d.

The detention time of the sewage in the septic tank was about 10 days i.e. a period of time much longer than the usual detention period of about 2-3 days recommended by literature (Salvato, 1958) and by the Ontario regulations for septic tank systems (Septic Tank Systems-1974). The long detention period was probably one of the reasons why relatively good sewage treatment effects were observed. Table 2 presents the concentrations of some contaminants in the background septic tank effluent samples as compared with those given by Bennett and Linstedt (1975) for toilet wastewater.

TABLE 2

Concentration of Some Contaminants in The Septic Tank Effluent as Compared with Literature Data.

Toilet Wastewater	Total phosphorus (as P) mg/l	Total Solids mg/l	Suspended Solids mg/l	Coliform Organisms counts/100 ml Total	Faecal
This study	19.6	596.7	80.1	0.19×10^6	0.11×10^6
Bennett and Linstedt (1975)	18.0	1400	650	$\sim 60 \times 10^6$	3×10^6

The longer detention time resulted in a lower level of total and suspended solids in the effluent and in lower concentration of coliform organisms, but did not affect the concentration of phosphorus in the septic tank effluent.

As the average concentration of phosphorus in the septic tank effluent was 19.6 mg/l (as P), the amount of phosphorus leaving the septic tank with the effluent was

$$\underset{\ell\ /\mathrm{p.d.}}{117.6} \times \underset{(\mathrm{mg/l})}{19.6} = \underset{\mathrm{mg/p.d.}}{2305} \quad \text{or} \quad 841 \text{ g/pers. year.}$$

The accumulation rate of the sludge, measured before alum was applied to the system, was 62.0 l/pers. year with an average concentration of phosphorus in the sludge equal to 610 mg/l. The phosphorus accumulated in the sludge amounted to about 38.0 g/pers. year, thus the total production rate of phosphorus by the residents was about 879.0 g/pers. year.

2.2 Sampling Procedure

Two kinds of sewage samples were tested:

1. Septic tank effluent samples taken weekly from the outlet of the septic tank (Fig. 1),
2. Sludge and supernatant samples taken every 4 to 6 months from the septic tank compartments.

A special sampler was designed for taking sewage samples from the septic tank contents and for measuring the depth of the liquid and the sludge in the tank. (Fig. 2). A transparent acrylic graduated cylinder 75 mm ID and 1.8 m in length was equipped with a hinged bottom. After the sampler was put vertically into the septic tank it was pressed to the bottom of the tank, closing the bottom lid and trapping the sample. The quality and quantity of the sewage and sludge left inside the sampler was thought to be fully representative of the septic tank contents. Sludge and supernatant samples were taken from the sampler through several drain cocks located at different heights from the bottom.

2.3 Selection of a Chemical for Combined Biological-Chemical Phosphorus Removal

In order to reduce the concentration of phosphorus in the septic tank effluent to 1.0 mg/l (as P) a proper chemical must be selected for precipitation of phosphorus to the bottom of the tank.

Aluminium sulfate (alum), lime or ferric chloride have recently been widely applied in municipal sewage treatment plants in North America and Europe for removal of phosphorus, BOD and suspended solids from sewage (Nilsson, 1961; Isgard, 1971; Bowman, 1975; and Cooper, 1975). Sweden has about 500 wastewater treatment plants using chemicals for phosphorus removal; 85 to 90% of the plants use alum. (Ulmgren, 1975).

Only one publication is known to this author on the use of phosphorus precipitating chemicals in subsurface sewage disposal systems. Barth et al (1969) added sodium aluminate directly to the filter medium through a dosing syphon. As a result the precipitated insoluble aluminium phosphate was concentrated on the surface of the filter medium.

Long and Nesbitt (1975) have compared the characteristics of two municipal plant effluents obtained by using alum and sodium

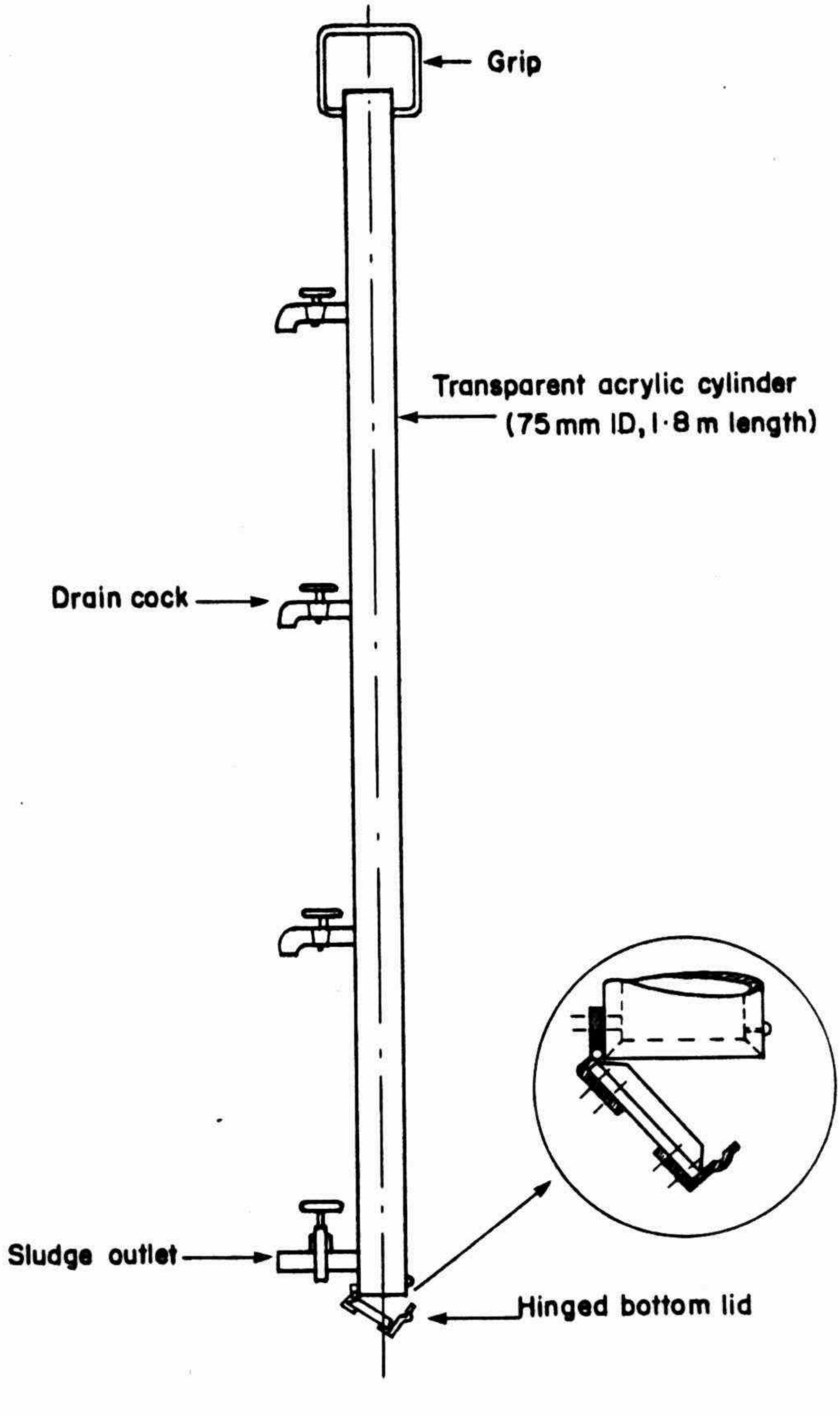

FIG. 2. SEPTIC TANK SLUDGE SAMPLER

aluminate. They found that the optimum addition of alum resulted in greater removal of phosphorus and organic matter than were experienced with the use of sodium aluminate.

Eberhardt and Nesbitt (1968) presented numerous examples showing that the dosing of alum resulted also in an increased removal of BOD and suspended solids. Hsu (1975) showed that phosphorus can be completely removed from solution when aluminium is present in large excess. Additional benefits of the use of aluminium salts and especially that of alum is their effect on removal of coliform organisms from sewage (about 80% removal) and on removal of the intestinal parasite ova and protozoa from the effluent (Nilsson 1969, Zenz and Piwnicka 1969). Alum in a solution form was therefore selected in this study for phosphorus removal from wastewater inside the septic tank.

Table 3 presents a summary of some reports on the efficiency of alum in removal of phosphorus and BOD from municipal sewage, however, one cannot simply compare the presented results with the effect of alum on septic tank effluent because of the difference in phosphorus concentrations. The concentration of phosphorus in municipal sewage is lower because the sewage is, in most cases, diluted with water from industry, food production etc. The most reasonable way to compare the effect of alum is to compare the Al:P ratios.

The Chemical precipitation of phosphate in waste treatment was surveyed and studied by Leckie and Stumm (1970) and by Cooper (1975). In accordance with the stoichometry of the reaction between the alum and the orthophosphates of the domestic wastewater a solid product $AlPO_4$ is formed:

TABLE 3. Removal of Phosphorus and BOD from Sewage by using Alum (Summary of Some Reports).

Sewage Treatment Plant.	Alum Dosage (mg/l)	Phosphorus Data		BOD_5 Data		Reference
		Conc. mg/l	Removal %	Conc. mg/l	Removal %	
Pilot Plant Treating forty-five litres per minute.	397[1)]	1.63	89.0	-	>86.0	Bennet et al, 1965.
University Sewage Treatment Plant (15 days of operation)	335[2)]	0.53	95.9	20.0	92.3	Eberhardt et al, 1968.
Pilot Plant at the Farum Sewage Plant in Denmark	225	1.27	87.4	-	-	Jørgensen et al, 1973.
Windsor Ont.Sewage Treatment Plant	90	1.0	86.5	42.0	61.0	Ockershausen, 1974.
Sewage Treatment Plant in Sweden (Lamellae Sedimentation Tanks used)	160	0.29	91.0	-	-	Isgard, 1971.
Balatonfüred Sewage Treatment Plant in Hungary	135	2.59	61.0	39.1	79.6	Dobolyi, 1973.
Pennsylvania University Sewage Treatment Plant.	173[2)]	0.61	91.9	16.0	77.8	Long et al, 1975.

1) $Al_2(SO_4)_3 \cdot 14\ H_2O$ - used

2) $Al_2(SO_4)_3 \cdot 18\ H_2O$ - used

$$Al_2(SO_4)_3 + 2PO_4^{-3} \longrightarrow 2AlPO_4 \downarrow + 3SO_4^{-2} \qquad \ldots.(1)$$

which precipitates to the bottom of the septic tank. The chemical reaction and the precipitation process are affected by the Al:P ratio in the solution and by the pH. Stumm (1964) calculated the solubility relationships for some orthophosphate crcystaline phases under different pH conditions. The $AlPO_4$ precipitate is in its lowest solubility level at pH 5.5 to pH 6.5 and those are the pH conditions for the optimum precipitation. As it follows from Eberhardt's and Nesbitt's (1968) experimental study at a constant Al:P ratio the total phosphorus in a filtered effluent is higher at pH 6.5 than at pH 5.5.

When the alum is added to domestic sewage in the presence of bicarbonate alkalinity an aluminium hydroxide floc is formed in accordance with following reaction:

$$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 \longrightarrow 2Al(OH)_3 \downarrow + 3\,CaSO_4 + 6CO_2 \uparrow \qquad \ldots.(2)$$

The aluminium hydroxide is in a form of a voluminous gelatinous floc which adsorbs colloidal particles providing clarification.

According to Leckie and Stumm (1970) some other reaction products like $Ca_{10}(PO_4)_6(OH)_2$ (hydroxyapatite) and $FePO_4 \cdot 2H_2O$ (strengite) are also formed as a result of the affinity between multivalent metal ions (Ca^{+2}, Fe^{+3}, Al^{+3}) and the orthophosphates in the sewage. All the above precipitated solids and flocs are components of the sludge removed later from the septic tank.

2.4 Dosing Rate of Aluminium Sulphate (Alum) for Removal of Phosphorus From the Septic Tank Effluent.

The aluminium sulphate (alum) used in the study was: $Al_2(SO_4)_3 \cdot 14H_2O$. The molecular weight of the alum is 594.4 and the weight of aluminium in one gram-molecule of alum is 53.96 grams; thus

11 g of alum must be introduced into the septic tank in order to add one gram of aluminium to the chemical reaction. According to the stoichiometry of reaction #1 given above, 0.87 g of aluminium would be required for the precipitation of one gram of phosphorus. In practice, however, the recommended aluminium to phosphorus ratio is in the order 2 to 3, depending on the phosphorus concentration in the wastewater and on the phosphorus concentration required in the final effluent (Culp and Culp, 1971). Nesbitt - 1969 in his review on phosphorus removal found that weight ratios from 1.7 to 2.3 are necessary to achieve good phosphorus removal with aluminium.

The average concentration of phosphorus in the septic tank effluent under study was 19.6 mg/l. The average amount of wastewater discharged into the septic tank with each flushing of the toilet was 22.8 litres[1)], therefore the amount of phosphorus which must be removed from the wastewater after each flushing was 446.9 mg.

When applying a ratio of Al:P = 2.0; 9831.8 mg of dry aluminium sulphate (alum) must be introduced into the septic tank with each flushing. The required dose of alum is about 430 mg/l. One 45.5 l (10 Imp. gal.) container filled with liquid alum (supplied by Allied Chemical Canada Ltd.[2)]) will contain 29.58 kilograms of dry alum and thus two such alum containers should be sufficient for a year long use by a three resident house.

2.5 Dosing Techniques

The procedure of dosing alum into the septic tank is shown in Figure 1. A plastic alum-filled container located in the basement

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1) 19.8 l from the toilet tank and 3.0 l from the bathroom sink.

2) See Allied Chemical Canada Bulletin 306-4: "Equipment and Piping for Liquid Alum at Ambient Temperatures".

of the two storey house was connected to a dosing device[1)] designed in such a way to have a given portion of liquid alum injected into the sewer piping with each flushing of the toilet water. The dosing device was activated by a 12-volt electric mercury switch fixed to the flushing mechanisms of each toilet. The alum injected was mixed in the sewer pipe with the fresh sewage coming from the toilet, the amount of liquid alum added to the septic tank was proportional to the wastewater flow.

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1. The design and operation of the dosing device developed by Mr. R. Foggett of the Applied Sciences Section, is at present being patented. Details will be made available at a later date.

3. RESULTS

3.1 General

One year prior to installing the device for regular dosing of alum, alum was added tentatively to the sewage by pouring a portion of liquid alum into the toilet bowl once daily. Despite a relatively high dosage of alum (708 mg/l) applied for a period of 43 consecutive days, the removal of phosphorus from the septic tank effluent was not higher than 74.5%. Considerable concentrations of SO_4 (up to 470 mg/l) and that of Al (up to 10 mg/l) were observed in the septic tank effluent indicating that a part of the alum was not involved in the phosphorus binding reactions. The observed insufficient phosphorus removal was attributed to the inadequate mixing of the alum with the sewage when using the manual dosing technique.

A better mixing was obtained only after a dosing device was installed which provided an automatic injection of alum into the end of the sewer pipe, with each flushing of the toilet.

A total of about 200 septic tank effluent samples and 12 sludge samples were collected and tested during the study. The concentrations of chemicals and coliform organisms in the effluent and in the sludge, before and after regular dosing of alum started, are presented in Tables 4 and 5. The sludge accumulation rate is shown in Table 6.

TABLE 4. EFFECT OF ALUM ON CONCENTRATION OF CONTAMINANTS IN SEPTIC TANK EFFLUENT

		CONCENTRATION OF CONTAMINANTS[1]				
		Before Using Alum		When Dosing Alum (105 to 430 mg/l)		Average at alum dosage 430 mg/l[2]
		Range	Average	Range	Average	
Phosphorus (as P)	Total	19 - 20	19.6	0.6 - 4.6	2.8	0.72
	Soluble	14 - 19	16.7	0.06 - 4.0	1.1	0.13
Solids	(Total	540 - 630	596.7	455 - 660	523.4	565.0
	(Suspend.	65 - 100	80.8	15 - 90	35.0	25.0
	(Dissol.	470 - 565	515.9	425 - 570	488.4	540.0
BOD_5		36 - 260	142.6	20 - 100	66.6	83.3
TOC		60 - 90	76.0	24 - 156	58.4	70.7
COD		Not tested	-	150 - 195	168.6	170.0
pH		7.4 - 8.7	7.9	7.0 - 7.7	7.2	7.2
Ammonia (as N)		105 - 150	130.8	90 - 130	108.8	118.3
Total Kjeldal		Not tested	-	100 - 170	123.0	130.0
Nitrite (as N)		0.01 - 0.05	0.02	<0.02	<0.02	<0.02
Nitrate (as N)		0.1 - 0.5	0.16	<0.2	<0.2	<0.2
Chlorides (as Cl)		94 - 106	100.2	70 - 114	90.6	112.0
Sulfates (as SO_4)		40 - 58	50.2	47 - 220	120.5	196.7
Aluminium (as Al)		0.18 - 1.80	0.61	1.00 - 4.90	2.37	1.3
Iron (as Fe)		0.60 - 0.90	0.72	0.25 - 1.50	0.67	0.27
Calcium (as Ca)		20.0 - 24.0	22.7	12.0 - 80.0	25.4	19.3
Magnesium (as Mg)		5.0 - 20.0	12.3	4.0 - 13.0	6.9	6.3
Sodium (as Na)		93.0 - 111.0	101.3	82.0 - 100.0	91.0	98.3
Potassium (as K)		36.0 - 43.0	38.5	29.0 - 35.0	32.5	36.7
Hardness (as $CaCo_3$)		40.0 - 128.0	78.3	66.0 - 118.0	82.5	73.0
Alcalinity (As $CaCO_3$)		636.0 - 674.0	667.8	390.0 - 556.0	484.3	429.5
El. Conductivity (μmho/cm)		970.0 - 1850.0	1712.7	1010.0 -2080.0	1623.4	1805.0
Total coliforms (counts/100 ml)		$2.5x10^3$-$820x10^3$	$191x10^3$	$5x10^3$-$850x10^3$	$125x10^3$	$8.0x10^3$
Fecal coliforms (counts/100 ml)		$1.8x10^3$-$740x10^3$	$111x10^3$	$1x10^3$-$150x10^3$	$23x10^3$	$<1.0x10^3$

1) All values are in mg/l except of coliform counts, pH and el conductivity

2) Al:P ratio ≅ 2.0

TABLE 5. EFFECT OF ALUM ON CHEMICAL AND BIOLOGICAL COMPOSITION OF SEPTIC TANK SLUDGE

CONCENTRATION OF CONTAMINANTS[1)]

		Before dosing alum		When dosing alum (average 430.0 mg/l)	
		I comp.	II comp.	I comp.	II comp.
Phosphorus	Total	610.0	18.0	1650.0	1300.0
	Soluble	1.7	2.8	2.5	2.7
Total Solids		23350	620	45610	41000
BOD_5		6000	380	3900	2000
TOC		N.T.[2)]	100	7700	3800
COD		N.T.	N.T.	32500	25500
pH		N.T.	8.4	7.0	7.0
Ammonia (as N)		19.0	22.0	170.0	180.0
Total Kjeldahl		2200.0	170.0	1200.0	1000.0
Nitrite (as N)		0.01	0.01	0.11	0.11
Nitrate (as N)		0.98	< 0.01	< 0.01	< 0.20
Chlorides (as Cl)		50.0	57.0	593.0	365.0
Sulfates (as SO_4)		28.0	19.0	120.0	130.0
Aluminium (as Al)		5.3	0.29	2700.0	1800.0
Iron (as Fe)		160.0	0.75	190.0	250.0
Calcium (as Ca)		66.0	22.0	49.0	41.0
Magnesium (as Mg)		10.0	6.0	48.0	6.0
Sodium (as Na)		55.0	53.0	110.0	99.0
Potassium (as K)		22.0	20.0	40.0	39.0
Total coliforms (counts/100 ml)		$0.9x10^6$	$0.42x10^6$	$5.0x10^6$	$1.0x10^6$
Fecal coliforms (counts/100 ml)		$0.9x10^6$	$0.11x10^6$	$1.8x10^6$	$0.1x10^6$

1) All data, except of pH and concentration of coliform organisms, are given in mg/l.

2) N.T. - Not Tested.

TABLE 6. SLUDGE ACCUMULATION RATE IN A TWO COMPARTMENT SEPTIC TANK

				BEFORE DOSING ALUM			WHEN DOSING ALUM[1)]		
			Oct. 10 1972	March 4 1974	July 22 1974	Jan. 14 1975	July 16 1975	Nov. 26 1975	June 2 1976
Septic Tank 3.4 m^3	I-st compartment (bottom area 2.033 m^2) sludge depth	cm		15.2	25.4	22.9	35.6	53.3	45.7
	sludge vol.	l	50.0[2)]	309.0	516.4	465.6	723.8	1083.6	929.1
	II-nd compartment (bottom area 0.810 m^2) sludge depth	cm		0	1.0	2.5	15.2	20.3	19.1
	sludge vol.	l	0	0	8.1	20.3	123.1	164.4	154.7
	Total Sludge volume (litres)	l	50.0	309.0	524.5	485.9	846.9	1248.0	1083.8
Increase in volume of sludge (litres)		l		259.0	215.5	-38.6	361.0	401.1	-164.2
Intervals between measurement (days)		d		510	140	176	183	132	188
Residents using system (persons)		p		3	3	3	3	3	3
Rate of sludge accumulation		l/p.d.		0.17	0.51	-0.07	0.66	1.01	-0.29

Average rate of sludge accumulation between Oct. 10 1972 and Jan. 14, 1975. (before dosing of alum started) 826 days. Total: 0.18 l/p.d. (I-compartment 0.17 l/p.d.; II-compartment 0.01 l/p.d.)

Average rate of sludge accumulation between Jan. 14, 1975 and June 2, 1976 (during regular dosing of alum) 503 days. Total: 0.40 l/p.d. (I-compartment 0.31 l/p.d.; II-compartment 0.09 l/p.d.)

1) Regular dosing of alum started on February 13, 1975.

2) The 50.0 litres of sludge were left for seeding purposes.

3.2 Removal of Phosphorus from Septic Tank Effluent

Regular dosing of alum by using the dosing device resulted in a considerable decrease in total and soluble phosphorus concentrations in the septic tank effluent. (Table 4). The average concentration of total phosphorus (2.8 mg/l) and soluble phosphorus (1.1 mg/l) observed after a twelve month period of dosing alum with an average dosage of 246.8 mg/l (between 105.0 and 430 mg/l) was considered to be too high for septic tank effluent which is intended to be suitable for discharge into a receiving water body. A dosage of alum of 430 mg/l (Al:P $\cong$ 2.0) was applied during the final 3 months period of the study resulting in a decrease in total and soluble phosphorus concentrations in the septic tank effluent to 0.72 mg/l and 0.13 mg/l respectively.

Higher removal of phosphorus may be obtained by additional polishing of the septic tank effluent by means of a small sand filter. As observed by Brandes et al (1975) a 48% removal of total phosphorus from septic tank effluent was obtained by using a sand filter 3.6 x 3.0 m and 1.2 m deep with sand of a grain size D_{10} = 0.24 mm and uniformity coefficient C_u = 2.8. A further reduction in total phosphorus concentration could be expected in the final effluent when using such a filter.

The removal of the soluble phosphorus from the septic tank effluent, observed after increasing the dosing rate of alum, was almost complete (99.2%) indicating that nearly all the soluble phosphorus in the septic tank effluent came into chemical reaction with the alum. The lack of soluble phosphorus in the effluent leaving the septic tank is of utmost importance because it is the inorganic orthophosphates in a dissloved form which are taken up from the water by algae and other living organisms

for use in basic metabolic processes (Katchman 1961).

The effect of the alum dosage and of Al:P ratios on the concentrations of the total phosphorus in the septic tank effluent are demonstrated in Fig. 3. The Al:P ratios were calculated from the amounts of alum injected inot the septic tank by the dosing device and from the average initial phosphorus concentrations in the septic tank effluent. Similar effect of Al:P ratios on phosphorus concentrations in effluent were reported by Long and Nesbitt (1975) and their results are plotted on the same graph (Fig. 3).

3.3 Effect of Alum on Accumulation Rate of Sludge

As anticipated, the removal of phosphorus, suspended solids and other contaminants from the septic tank effluent obtained after using alum caused an increase in sludge accumulation rate as compared to the normal accumulation rate observed before alum was used. The accumulation of sludge in both of the compartments of the septic tank observed during the 44 month period of the study is shown in Talbe 6 and in Fig. 4.

Before using alum (i.e. between Oct. 10, 1972 when the septic tank was pumped out, and March 4, 1974 when the first portion of liquid alum was poured into the septic tank) the average sludge accumulation rate was 0.17 l/p.d. Weibel et al (1949) reported an average sludge sludge accumulation rate of 0.16 l/p.d. observed after the first two years of operation of 205 septic tanks. The authors reported also a drop in the observed accumulation rate after 4 to 6 years of septic tank operation and attributed the drop to the digestion and compaction processes going on in the septic tank.

When using alum, which promotes the chemical flocculation and compaction in the septic tank, a drop in sludge accumulation rate can be expected to start earlier. In fact, as it is demonstrated in Fig. 4

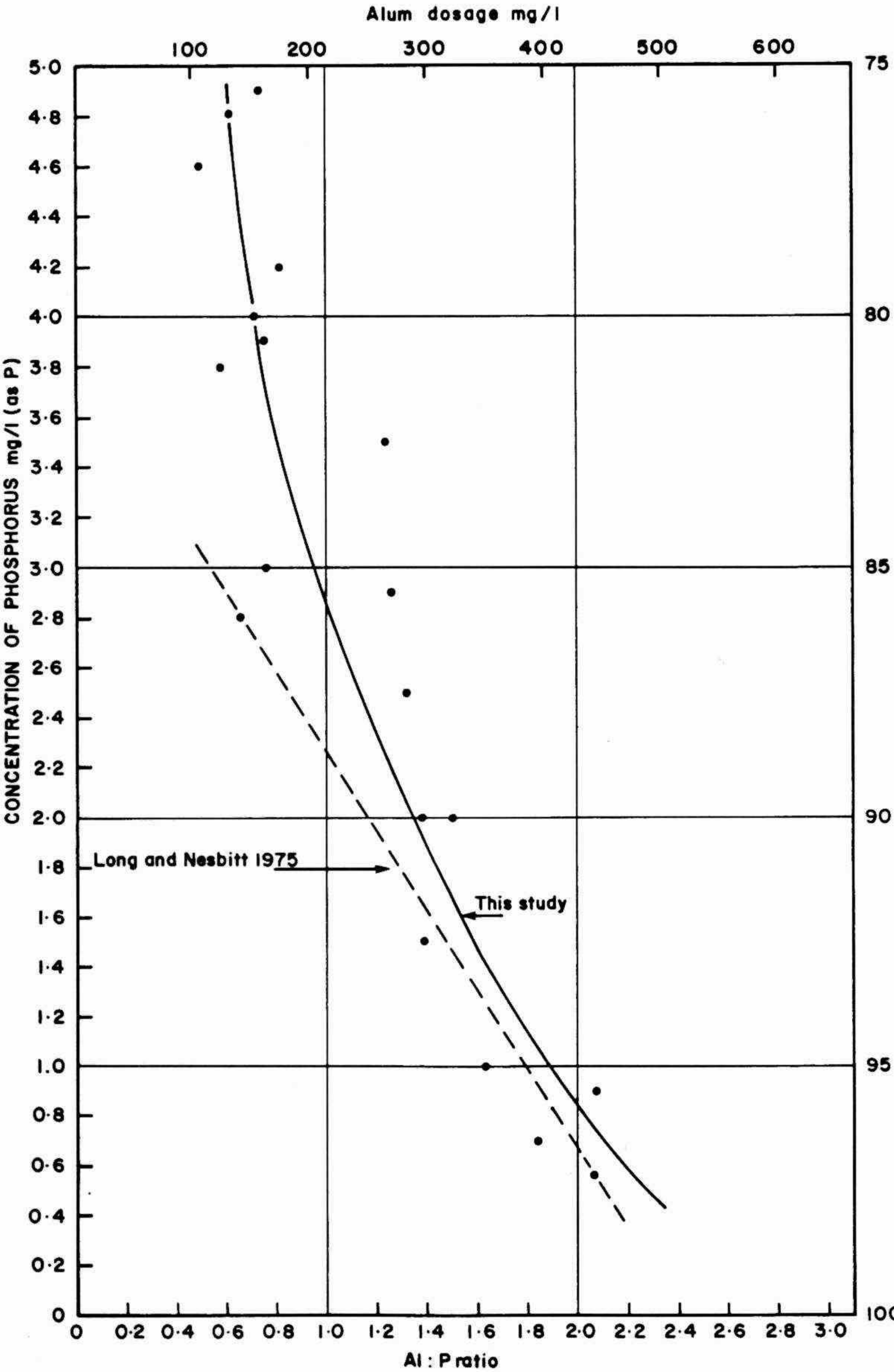

FIG. 3. EFFECT OF Al : P RATIO ON CONCENTRATION OF PHOSPHORUS IN SEPTIC TANK EFFLUENT.

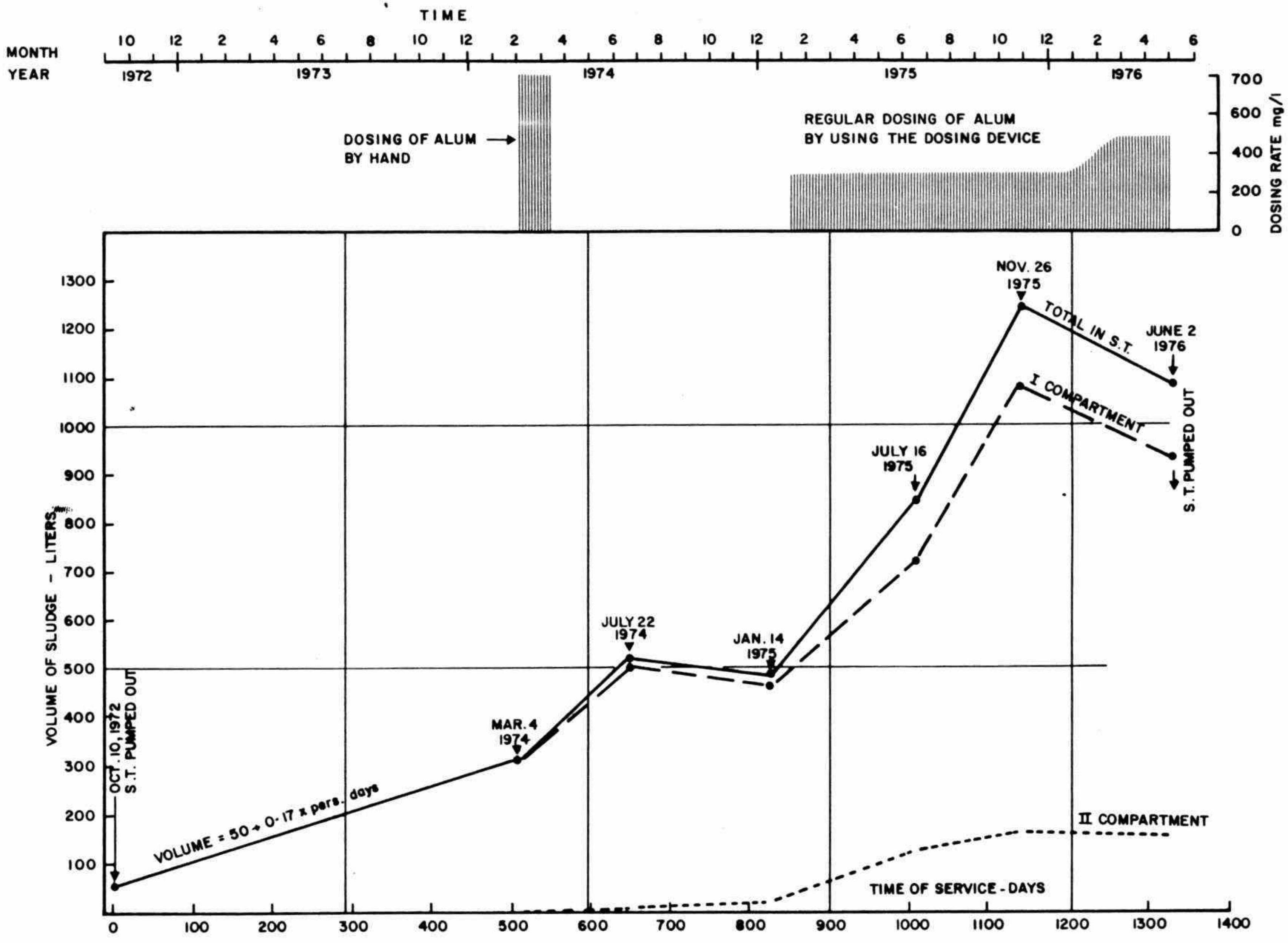

FIG. 4. SLUDGE ACCUMULATION IN SEPTIC TANK (S.T.)

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the use of alum caused initially an increase in the sludge accumulation rate after March 4, 1974 and after January 14, 1975 and then after about 4 and 10 months respectively of continuous dosing of alum, a drop in accumulation rate of sludge was observed. The density of the sludge increased considerably. The sludge collected on June 2, 1976, i.e. at the end of the alum dosing experiment, was black in colour and of such a high consistency that it could hardly flow out by gravity from the 10.0 mm I.D. outlet of the sampler. The black colour of the sludge can be attributed to the Iron Sulphides created in anaerobic conditions in the septic tank as a result of the Aluminium Sulphate - Iron interactions. No failure in the operation of the leaching bed of the system was observed after 44 months of this study.

An increase in sludge density and a decrease in sludge volume were observed by Eberhart et al (1968), Zenz et al (1969), Grigoropoulos et al (1971), Minton et al (1972), Finger (1973) and Dobolyi (1973) after using alum for phosphorus removal in sewage treatment plants. Minton et al (1972) reported that the addition of alum during full scale plant tests resulted in a rapid decrease in the sludge volume index (SVI) from 130 to 75 almost doubling the sludge density.

In this study, the average sludge accumulation rate (Table 6), determined after a 16 month period of regular dosing of alum, was 0.4 l/p.d. i.e. 2.35 times higher than the sludge accumulation rate of 0.17 mg/p.d. observed before using alum. The production of wastewater by the residents using the system was almost constant (117.6 l/p.d.) throughout the study period, consequently, the amount of wastewater, from which one litre of sludge was precipitated, dropped from 691.8 litres, before using alum, to 294.0 litres when alum was applied.

Simple calculations have shown that the sludge should reach the maximum permissible level in the first compartment of this septic tank[1) not earlier than after a period of about 4.4 years of regular dosing of alum. (Appendix).

If similar calculations, as used in the Appendix, are applied to determine the time interval between cleanings of a 500 gallon (2270 litres) septic tank constructed in accordance with the Ontario recommendations (Septic Tank Systems - 1974) the time interval should be as long as 3.8 years, if alum is not used, and not less than 2.1 years if alum is regularly dosed at an optimum level to the septic tank. The permissible level of sludge, used in the calculations was applied only to the first compartment of the septic tank.

The determined sludge accumulation rates in the first and second compartments of the septic tank have shown that if a septic tank is built in accordance with the existing regulations (Septic Tank Systems - 1974, Manual of Septic Tank Practice - 1967) the sludge in the first compartment will start to overflow to the second compartment long before the top of sludge in the second compartment will reach the "permissible" level. Consequently, the restrictions for the "permissible" level, shown in the regulations, must apply to the first compartment only. In order to avoid overflow of sludge, and consequently failure of leaching bed, provisions should be made to have an apparatus or device capable of indicating when the sludge reaches the permissible level in the septic tank.

3.4 Balance of Phosphorus in the Septic Tank System

It was of interest to determine the distribution of the phosphorus between the septic tank effluent and the sludge before and after using alum and to determine the average yearly per capita production of phosphorus by the residents.

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1) The minimum permissible distance between the top of the sludge and the bottom of the outlet fitting is restricted by septic tank regulations.

after using alum and to determine the average yearly per capita production of phosphorus by the residents.

Two periods of the study were selected for comparison: one period between October 10, 1972 and March 4, 1974 when no alum was used in the study and one period between July 16 and November 26, 1975 when regular dosing of alum into the septic tank took place. The phosphorus balance is presented in Table 7.

It appeared that only 4.3% of the total phosphorus was settled and accumulated in the sludge before alum was used, the rest of the phosphorus (95.7%) left the septic tank with the septic tank effluent entering the leaching bed. After dosing of alum with average dosages 246.8 mg/l, the portion of total phosphorus settled and accumulated in the sludge increased to 84.9% and only 15.1% of the phosphorus left the septic tank with the effluent. After the dosage of alum was already at 430 mg/l the portion of phosphorus leaving the septic tank dropped to about 4.0% of the phosphorus introduced into the system.

As it follows from Table 7, before alum was used the amount of phosphorus produced was 2.41 g/p.d. or 879.7 g/p. year, after the dosing of alum was applied the amount of phosphorus was 2.18 g/p.d. or 795.7 g/p. year. The 10% difference is a result only of the inaccuracy of the experiment.

3.5 Precipitation of Solids in the Septic Tank

The dosing of alum at average doses of 246.8 mg/l caused a 12.3% decrease in concentration of total solids in the septic tank effluent and a 56.7% decrease in suspended solids. (Table 4). At the same time the concentration of total solids in the sludge was almost doubled (from 23,350 mg/l to 43,162.4 mg/l) and the amount of total solids precipitated from one litre of sewage increased from 33.8 mg to 370.7 mg. The observed increase in total solids precipitation was a

TABLE 7. BALANCE OF PHOSPHORUS IN THE SEPTIC TANK SYSTEM

		Units	Before Using Alum (3 persons, 510 days) Oct. 10, 1972	March 4, 1974	Phosphorus Accumulation	After Using Alum (3 persons, 132 days) July 16, 1975	Nov. 26 1975	Phosphorus Accumulation
I-Compartment	Volume of Sludge	l	50.0	309.0		723.8	1083.6	
I-Compartment	P-Concentr. in sludge	mg/l	610.0	610.0		1600.0	1600	
I-Compartment	Phosphorus in sludge	g	30.5	188.5	158.0	1158.1	1733.8	575.7
II-Compartment	Volume of sludge	l	0.0	0.0	0.0	123.1	164.4	
II-Compartment	P.Concentr. in sludge.	mg/l	-	-	-	1000.0	1700.0	
II-Compartment	Phosphorus in sludge	g	-	-	-	123.1	279.5	156.4
Septic tank effluent		l	180×10^3			45.6×10^3		
P. concentration in effluent		mg/l	19.6			2.8		
Amount of P. in effluent.		g	3528.0		3528.0	130.4		130.4
Phosphorus in the system		g			3686.0			862.5
P. production rate.		g/p.d.			2.41			2.18

result not only of all the chemical and physical processes originated by the alum but also by the mass of dry alum added to the system. The balance of the total solids in the septic tank system is shown in Table 8. The determined build-up of the total solids in the system (31,004.4 mg/p.d.) was higher than the rate of dry alum addition (29,023.7 mg/p.d.) by about 2000 mg/p.d. (or 6.0%) of solids which settled to the bottom of the tank as a result of physical and chemical processes other than the direct chemical alum reactions.

3.6 Effect of Alum on Removal of Coliform Organisms from the Septic Tank Effluent

The concentrations of total and faecal coliform organisms in the septic tank effluent before using alum were lower than usually observed in other septic tanks (Bennett and Linstedt, 1975, Brandes et al - 1975). The reason of lower concentrations is attributed to the relatively long detention time of the sewage in the septic tank under study.

When adding alum at an average dosing rate of 246.8 mg/l the concentration of the total coliform organisms in the septic tank effluent dropped from an average of 191,000 to 125,000 counts/100 ml (35% removal) and the faecal coliforms from 111,000 to 23,000 counts/100 ml (about 80% removal). (Table 4). An 80% reduction in coliform organisms in sewage was also observed by some Swedish investigators after applying aluminium salt for precipitation of phosphorus, (Nilsson - 1969).

Further increase of the dosage of alum to 430.0 mg/l caused a removal of total coliform organisms to a concentration of

TABLE 8. BALANCE OF TOTAL SOLIDS (TS) IN THE SEPTIC TANK SYSTEM

Septic Tank Contents		Before Using Alum Oct. 10, 1972 to March 4, 1974			When Using Alum (July 16 to November 26, 1975)			Build up of TS in the System mg/p.d.
		Average rate l/p.d.	TS concentra-ion. mg/l	TS rate mg/p.d.	Average rate l/p.d.	TS concentra-ion. mg/l	TS rate mg/p.d.	
Supernatant		117.6	596.7	70171.9	117.6	523.4	61551.8	-8620.1
Sludge	I-compartment	0.17	23350	3969.5	0.91	43400	39494.0	
	II-compartment	0.0	-	0.0	0.10	41000	4100	
	Total	0.17 1)		3969.5	1.01 1)		43594.0	39624.5
Supernatant and Sludge				74141.4			105145.8	31004.4

Average dosing rate of aluminium sulphate (alum) - 246.8 mg/l
Amount of dry alum introduced while dosing - 246.8 x 117.6 = 29023.7 mg/p.d.

1) Production rate of sludge see Table 6, l-litres, p-person, d-days.

8000/per 100 ml (~96.0% removal) and of faecal coliform organisms to less than 1000 per 100 ml, (more than 99.0% removal)

The maximum permissible limits for total and faecal coliform organisms in raw water sources of drinking water are 5000 and 500 per 100 ml respectively. (Guidelines and Criteria - 1972).

As shown by Brandes et al (1975) a 1.2 meter deep sand filter was able to remove about 90% of the coliform organisms from septic tank effluent and thus effluent like that obtained in this study could easily undergo an additional polishing treatment to make the final effluent acceptable for being discharged into ground water or open water supplies.

3.7 The Fate of Aluminium and Sulphates in the Septic Tank System

The average concentration of aluminium in the supernatant and in the sludge, before using alum, was 0.61 mg/l and 5.30 mg/l, respectively. An increase in concentration of aluminium to 2.37 mg/l in the septic tank effluent and to 2700 mg/l in the sludge of the first compartment and to 1800 mg/l in the sludge of the second compartment was observed after a nine months period of dosing alum into the septic tank. A complete balance of aluminium before using alum and after nine months of dosing alum is presented in Table 9. As may be inferred the build up of aluminium in the system is exclusively due to the dosing of alum into the septic tank. The difference between the amount of aluminium built up in the system (2843.1 mg/p.d.) and the amount introduced by dosing (2638.0 mg/p.d.) (Table 9) is probably due to experimental inaccuracy (~7%).

An average increase in concentration of sulphates (SO_4) in the septic tank effluent from 50.2 to 120.5 mg/l and an increase

TABLE 9. BALANCE OF ALUMINIUM IN THE SEPTIC TANK SYSTEM

Septic Tank Contents		Before using alum (Oct. 10, 1972 to March 4, 1974) Average rate l/p.d.	Al concentr. mg/l	Al rate mg/p.d.	Using Alum (July 16, 1975 to Nov. 26, 1975) Average rate l/p.d.	Al concentr. mg/l	Al rate mg/p.d.	Build up of aluminium in the system mg/p.d.
Supernatant		117.6	0.61	71.7	117.6	2.37	278.7	207.0
Sludge	I-compartment	0.17	5.30	0.9	0.91	2700.0	2457.0	
Sludge	II-compartment	0.0	-	0.0	0.10	1800.0	180.0	
Sludge	Total	0.17 [1)]		0.9	1.01 [1)]		2637.0	2636.1
Supernatant and Sludge				72.6			2915.7	2843.1

Average dosing rate of aluminium sulphate (alum) - 246.8 mg/l

Amount of aluminium introduced while dosing alum - $\frac{246.8}{11} \times 117.6 = 2638$ mg/p.d.

1) Production rate of sludge see Table 6, l-litres, p-person, d-days.

SO_4 concentration in the sludge from 28.0 to 120 mg/l was observed (Tables 4 and 5). The permissible concentration of SO_4 in drinking water is 250 mg/l (Guidelines and Criteria - 1972) i.e. about 2 times higher than in the septic tank effluent. No adverse effect of the SO_4 on the concrete septic tank and on the normal operation of the leaching bed was observed.

3.8 Effect of Alum on Concentration of Some Other Contaminants in the Septic Tank Effluent and in the Sludge

The settling of organic matter and insoluble metallic compounds to the bottom of the septic tank, when using alum (Table 5), resulted in clarification of the septic tank effluent and consequently, in an increase in the sludge mass.

The removal of BOD_5 was not as high as expected with alum addition (Table 4); only 41.6% of the BOD_5 was removed from the septic tank effluent. A considerable increase in concentration of total organic carbon (TOC) of up to 7700 mg/l was observed in the sludge, the decrease in TOC in the septic tank effluent was negligible (~ 7%). The chemical oxygen demand (COD) was not tested before alum was used but a very high concentration of COD of up to 32,500 mg/l was observed in the sludge when alum was used.

A 63% drop in concentration of iron in the septic tank effluent and an increase by 19% in the sludge was observed. A considerable accumulation of sodium, potassium and chlorides was observed in the sludge.

A decrease in pH in the septic tank effluent (from 7.9 to 7.2) and in the sludge (from 8.4 to 7.0) was caused by the alum which is acidic.

The nitrogen compounds and the calcium and magnesium concentrations were not noticably affected by the use of alum. (Tables 4 and 5).

3.9 Relationships Between Some Indicators of Contamination in the Septic Tank Effluent

Relationships between concentrations of some contaminants in the septic tank effluent and the effect of these contaminants on the physical properties of the effluent seem obvious. A linear relationship between the insoluble phosphorus (which is a difference between the total and soluble phosphorus) and the suspended solids as well as a relationship between the electrical conductivity and the dissolved solids in the effluent were observed. The effect of the use of alum on the above relationships was negligible. Figure 5 and 6 present the above relationships. The "goodness of fit" (r^2) shown on the graphs is high. The practical meaning of the graphs is that the determination of one indicator can provide information on concentration of the other e.g. a simple measurement of the electrical conductivity of the septic tank effluent can provide information on the concentration and range of the dissolved solids in the effluent.

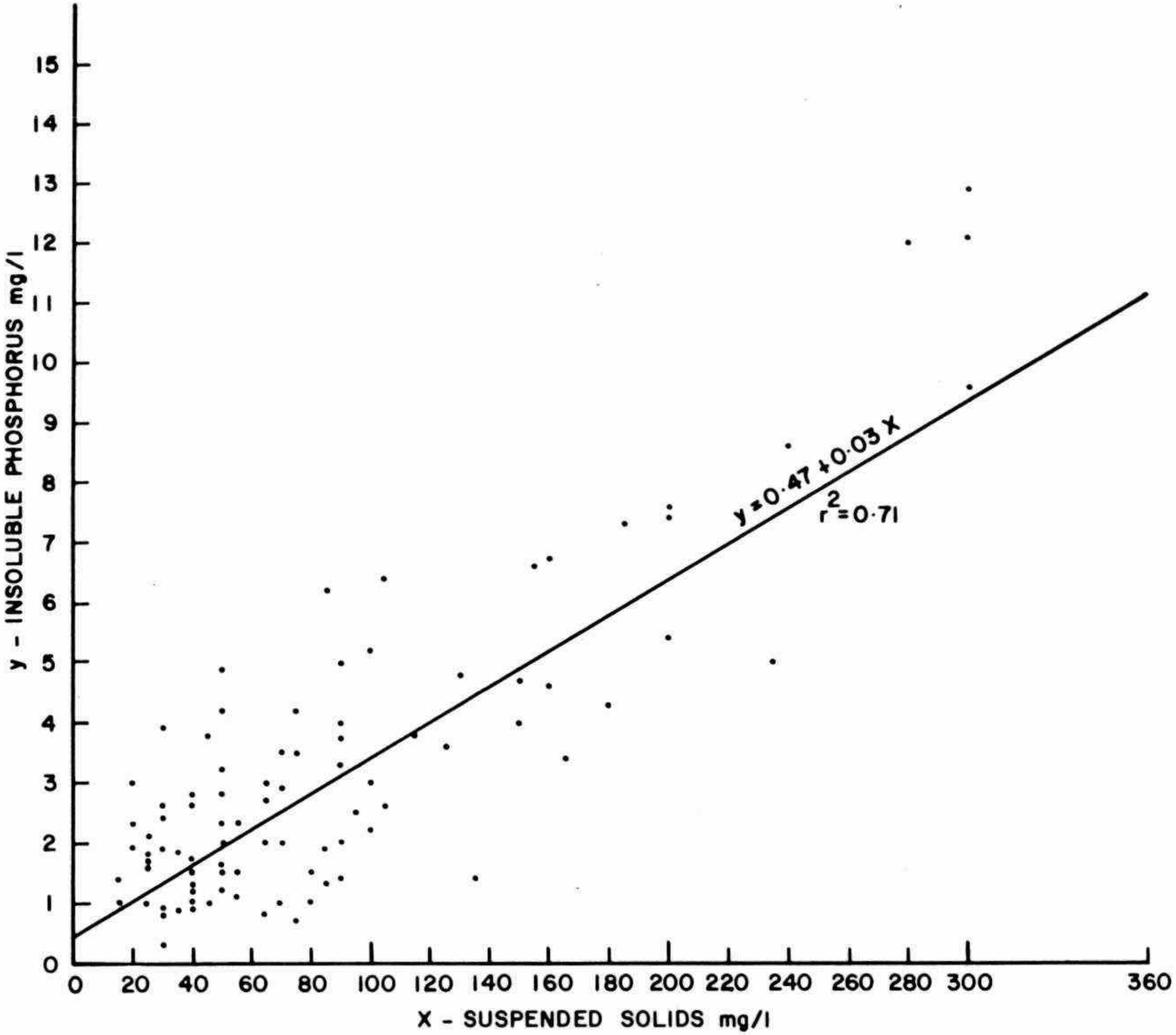

FIG. 5. RELATIONSHIP BETWEEN CONCENTRATIONS OF INSOLUBLE PHOSPHORUS AND SUSPENDED SOLIDS IN SEPTIC TANK EFFLUENT. (Insoluble P = Total P less Soluble P)

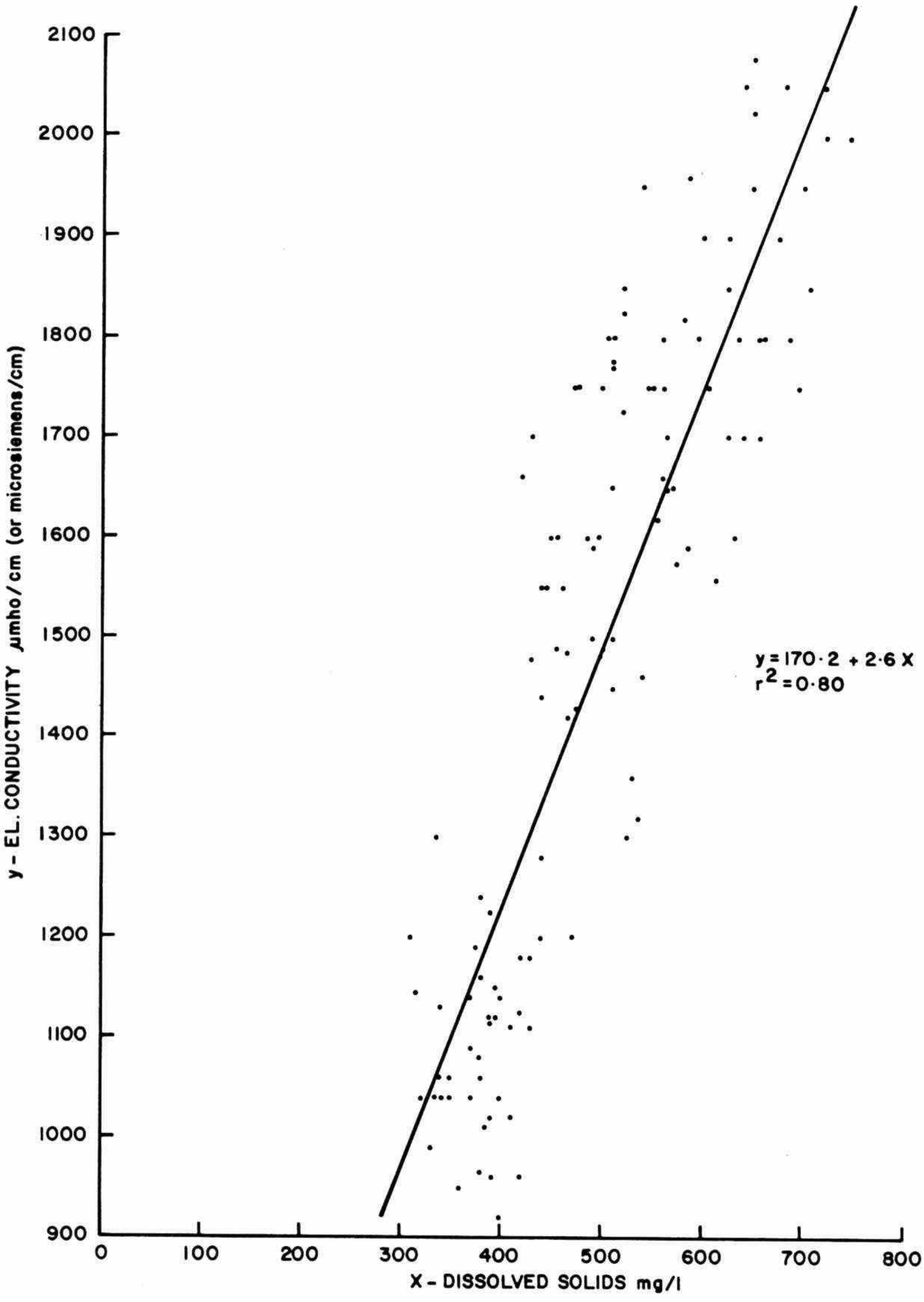

FIG. 6. RELATIONSHIP BETWEEN CONDUCTIVITY AND DISSOLVED SOLIDS IN SEPTIC TANK EFFLUENT.

4. PROCESS COSTS

Practical application of the alum dosing process can be successful only if the costs of the alum and the cost of installing the dosing system are within reasonable limits.

The average wastewater flow in North America is, according to Bennett (1975), 168.8 l/pers. day, and the average phosphorus concentration in domestic wastewater is about 15.0 mg/l. The optimal aluminium to phosphorus ratio obtained in this study is Al:P = 2, thus the amount of dry alum required for a 96% phosphorus removal (Fig. 3) is:

$$168.8 \times 15.0 \times 2.0 \times 11.0 = 55704 \text{ mg/pers. day}$$

where the number "11" used is the weight relation between alum and aluminium.

The required amount of dry alum is therefore

20.33 kg/pers. year

At a price of $0.22/Kg of dry alum (as of July 1976) the cost of alum is $4.47/pers. year.

The cost of installing the alum dosing system can be estimated as about $100.00 per dwelling.

5. SUMMARY AND CONCLUSIONS

1. The applied techniques of dosing alum to a septic tank, with each flushing of the toilet, ensures a good mixing of the alum with the sewage and a constant alum feed proportional to the wastewater flow.
2. The regular dosing of alum resulted in an increased removal of total and soluble phosphorus, total and suspended solids, coliform organisms, BOD_5 and many other contaminants from the septic tank effluent. At the same time the concentration of contaminants in the sludge increased accordingly. The average removal of the total and soluble phosphorus was 85.7% and 93.4% respectively at an average alum dosage of 246.8 mg/l. When a dosing rate of alum of 430.0 mg/l was applied (Al:P $\cong$ 2.0) the removal of the total phosphorus from the septic tank effluent increased to 96.3% and that of the soluble phosphorus to 99.2%.

   Further polishing of the septic tank effluent by using a relatively small sand filter could result in enhanced removal of the total and soluble phosphorus and BOD from the final effluent before it reached the ground or surface waters.
3. The average removal of BOD from the septic tank effluent was only 53.3%. Further increase in the dosing rate did not increase the BOD removal.
4. After dosing alum at an average rate of 246.8 mg/l the average concentration of the total and faecal coliform organisms in the septic tank effluent dropped to 125,000 and 23,000/100 ml

respectively. However, when a higher dosing rate of 430.0 mg/l of alum was used the total and faecal coliform organisms dropped to 8000 and to less than 1000/100 ml respectively. Further polishing of the septic tank effluent may be required.

5. Before using alum one litre of sludge was precipitated from about 692 litres of sewage. After the alum was applied only 294 litres of sewage were required for the same sludge production. The dosing of alum at an average rate of 246.8 mg/l caused an increase in concentration of the total solids in the sludge from 23350 mg/l to 43162 mg/l. The amount of total solids precipitated from one litre of sewage increased from 33.8 mg to 370.7 mg, an increase due mostly to the mass of alum added.
6. The use of alum initially caused an increase in sludge accumulation rate and then a drop after about 10 months of alum dosing was observed. The average sludge accumulation rate in the septic tank increased from 62.1, before using alum, to an average of 146.0 l/p.y. after a period of about 16 months of regular dosing of alum.
7. Regular dosing of alum to a septic tank which was used all the year round, caused a reduction in the time interval between tank cleanings from 5 to 2-3 years.
8. The process costs are of about $4.50/person year and only a small area is required for installation of the alum container and for the dosing device (usually in the basement of the house.

9. It seems reasonable to amend the existing septic tank regulations in such a way that if a septic tank consists of more than one compartment the recommended permissible distance between the top of the sludge and the bottom of the outlet fitting applied to the first compartment only. Provisions should be made to have a device capable of indicating when the sludge reaches the permissible level.

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APPENDIX

Calculation of required time intervals between septic tank cleanings after using alum for phosphorus removal.

A. Permissible volume of sludge (V_p) to be accumulated in the I-compartment of the septic tank:

$$V_p = A_1 (h_s - h_p)$$

where: A_1 - bottom area of the I-compartment of the septic tank (A_1 = 2.033 m^2)

h_s - total depth of sewage in the I-compartment (h_s = 1.20 m)

h_p[1] -permissible distance between top of sludge and bottom of the outlet fitting ("sludge clear space") - (h_p = 0.46 m)

V_p = 1504 litres

B. Average sludge accumulation rate in the I-compartment of the septic tank (between Jan. 14, 1975 and June 2, 1976) - 0.31 l/p.d.

C. Number of persons using the septic tank - 3

D. Time interval between cleanings:

$$t = \frac{1504}{0.31 \times 3 \times 365} = 4.4 \text{ years}$$

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1) The existing North American Septic Tank Regulations do not specify to which of the septic tank compartments does the restricted distance h_p apply.